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14. ABSTRACT
The objective of this effort was to evaluate automatic particle counters for use in monitoring aviation fuel cleanliness at Fort Campbell Airfield. Online and and laboratory instrumentaiton were both evaluated during the week long demonstration. Based on this evaluation it was determined light obscuration particle counter technologies are able to properly measure solid particles and provide an indication of particulate content levels present in fuels, and may be an appropriate replacement for the Army's existing filter effectiveness testing.

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Fuel, JP-8, Automatic Particle Counter, cleanliness, free water, Diesel

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-Technical Report-

Field Evaluation of Particle Counter Technology for Aviation Fuel Contamination Detection – Fort Campbell

Joel Schmitigal
Jill Bramer

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June 2013

U.S. Army Tank Automotive Research, Development, and Engineering Center
Detroit Arsenal
Warren, Michigan 48397-5000

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Jill Bramer
Force Projection Technology

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1. **Introduction**

Fuel quality assurance is accomplished by conducting periodic fuel sampling for the condition monitoring of aviation fuel by detecting, measuring, and reporting the levels of contaminants in the fuel. The currently accepted methods for measuring particulate and free water contamination of fuel supplies include:

- ASTM D2276 - Standard Test Method for Particulate Contaminant in Aviation Fuel by Line Sampling
- ASTM D3240 – Standard Test Method for Undissolved Water in Aviation Turbine Fuels
- ASTM D4176 – Standard Test Method for Free Water and Particulate Contamination in Distillate Fuels (Visual Inspection Procedures)

The current methods have several drawbacks including operator subjectivity, lack of detailed analysis, limitations in providing reliable data, and the turn-around time needed to get the test results.

The U.S. Army maintains the mission of providing quality fuel to all U.S. and Allied troops in tactical environments. Presently, requirements as outlined require a dedicated group of specifically trained fuels personnel to perform several tests per day per installation, looking for traces of sediment and water in the fuel (1)(2)(3).

Current standards, such as MIL-STD-3004, Department of Defense Standard Practice for Quality Assurance/Surveillance for Fuels, Lubricants, and Related Products and Field Manual No. 10-67-2, Department of the Army Manual for Petroleum Laboratory Testing and Operations, specifies limits for free water and particulate matter in aviation fuels. Specifically, free water contamination in jet fuel cannot exceed 10 parts per million (PPM) (2) and particulate matter contamination cannot exceed 2.0 mg/L for Intra-Governmental transfer receipts and 1.0 mg/L on issue to aircraft, or up to 10 mg/L for product used as a diesel product for ground use (1). Free water contamination (droplets) may appear as fine droplets or slugs of water in the fuel systems. The particulate matter found in field fuel systems varies in shape and is commonly found in the 5 to 40 micron size range. Common particulate matter includes silica, rust, metal shavings, fibrous materials, coatings material including paint, elastomeric materials, hydrocarbon/oxidation materials, and any other solid matter. At a minimum free water and particulate by color (as specified in the appendix of ASTM D2276) are checked daily, while filter effectiveness is checked every 30 days by gravimetric analysis (ASTM D2276).

The use of particle counting and automatic particle counters is prevalent in the hydraulics/hydraulic fluid industry. The International Organization for Standardization (ISO) has published several methods and test procedures for the calibration and use of automatic particle counters. The transition of this technology to the fuel industry is relatively new and several organizations (military and commercial) have conducted testing to ensure the transition from the hydraulic fluid market to fuels is viable.

In recent years, the United Kingdom (UK) based, Energy Institute (EI) published standards relating to fuel quality measurement using sensors. The first edition of EI 1570 Handbook on electronic sensors for the detection of particulate and/or free water during aircraft refueling was published in August 2012, and the second edition of EI 1598 Design, functional requirements and laboratory testing protocols for electronic sensors to monitor free water and/or particulate matter in aviation fuel was published in February 2012. In addition to the handbooks, the EI has also developed three (3) standard test procedures and methods for evaluating the particulate matter of fuels using electronic sensors; IP 564, IP 565, and IP 577.

- IP 564 – Determination of the level of cleanliness of aviation turbine fuel – Laboratory automatic particle counter method
- IP 565 – Determination of the level of cleanliness of aviation turbine fuel – Portable automatic particle counter method
- IP 577 – Determination of the level of cleanliness of aviation turbine fuel – Automatic particle counter method using light extinction

Military aviation fuels meeting the requirements of DEF STAN 91-91 (UK) (4) and MIL-DTL-83133 (US) (5) both include a report only requirement for particle counting. Particulate contaminate limits using particle counters are being developed as test programs and field demonstrations are in progress.

The U.S. Army and U.S. Navy have conducted laboratory evaluations of particle counter technologies for fuel contamination monitoring. The particle counters tested were unable to adequately distinguish between free water and sediment contamination. Conclusions from the laboratory evaluation indicated that particle counters cannot replace current technology where quantification of both free water and sediment contamination is required. However, this technology showed significant promise for monitoring overall fuel quality. To simplify the reporting of particle counter data, the International Organization for Standardization created Cleanliness code 4406:1999 (6). Several interested parties, both commercial and military, have proposed limited based on light obscuration particle counting technologies based on ISO 4406, provided in Table 1 and references (7)(8)(9)(10)(11)(12)(13)(14). As a result of the laboratory testing conducted, the U.S. Army has proposed a working cleanliness limit (based on ISO 4406) of 19/17/14/13 utilizing the 4μm (c)/ 6μm (c)/ 14μm (c)/ 30μm (c) size channels (9). The U.S. Army has included the 30μm size to detect free water in the fuel.

	Receipt	Vehicle Fuel Tank	Fuel Injector
Aviation Fuel			
DEF (AUST) 5695B		18/16/13	
Parker	18/16/13	14/10/7	
Pamas/Parker/Particle Solutions	19/17/12		
U.S. Army	19/17/14/13*		
Diesel Fuel			
World Wide Fuel Charter 4th		18/16/13	
DEF (AUST) 5695B		18/16/13	
Bosch/Cummins		18/16/13	
Donaldson	22/21/18	14/13/11	12/9/6
Pall	17/15/12	15/14/11	12/9/6 11/8/7

Table 1. Proposed Particle Counter Limits
***addition of 30 micron channel proposed by U.S. Army for detection of free water.**

2. Project Background

Defense Logistics Agency – Energy (DLA-E) funded a Tri-Service Field Evaluation of Automatic Particle Counters (APC). Each Service chose two (2) locations to conduct testing. The U.S. Army chose to conduct testing at Campbell Army Airfield (CAA) at Fort Campbell, KY and three airfields at Fort Rucker, AL. This report will only contain the test data collected at CAA during the week of 8-12 April 2013.

Once the locations were selected, TARDEC conducted site surveys at both locations in January/February 2013, to document the fuel distribution systems, ensure connections were available for the instruments, and to identify a location for testing of the laboratory based instruments.

The field evaluation included two types of particle counters: on-line instruments and portable laboratory based instruments. The online instrument chosen for this demonstration was the Parker Hannifin IcountOS, Figure 1, which will be called IOS throughout the report. The IOS instruments were designed to plug into existing sampling ports and extract a fuel sample during fuel flow. These instruments are capable of pumping the fuel back into the supply lines; thus creating no waste fuel. The IOS instruments run every 2 minutes and automatically collect and store data. Ideally, these instruments can be left in the field to monitor and collect data for fuel transfers. Due to the low frequency of fuel transfers at the U.S. Army locations, the IOS units were configured to only pull fuel samples from the supply lines and were initiated manually by the operators for each data set. The IOS units were moved from location to location as needed.

The second type of particle counter utilized in this demonstration consisted of portable laboratory based instruments used to evaluate contamination levels of bottle samples taken from select locations at CAA. The laboratory instrumentation, Figure 2, utilized included:

- 2 Parker Hannifin ACM20 instruments meeting IP 564
- 2 Pamas S40 AVTUR instruments meeting IP 565
- 1 Stanhope-Seta AvCount meeting IP 577

All instruments were calibrated to ISO 11171, and reported cleanliness codes based on ISO 4406. Cleanliness levels were represented by 4µm, 6µm, and 14µm size channels respectively. The 30µm channel was also reported for the Parker Hannifin ACM20 instruments and the Stanhope-Seta AvCount instrument because the prior work has indicated that the 30µm channel may contain pertinent information relating to free water content (9). During this evaluation, the Pamas S40 AVTUR instrument did not have the capability of providing 30µm channel data.

Figure 1. Parker IcountOS inline instrument

Figure 2. Laboratory instrumentation 2 Pamas S40 AVTUR instruments (foreground), Stanhope-Seta AvCount (back left), 2 Parker Hannifin ACM20 instruments (back right)

A sampling manifold was constructed to ensure the particle counters tested the same fuel from the same location in the bottle sample. Additionally, each bottle sample was hand rolled for 1 minute to ensure the particles were homogeneously distributed throughout the sample without introducing air bubbles. Each bottle sample was tested in duplicate and agitated in between runs.

3. **Approach**

The field demonstration at Campbell Army Airfield was conducted during the week of 8-12 April 2013. The demonstration focused on fuel deliveries at the CAA bulk fuel storage facility, fuel transfers from bulk fuel storage to the fueling facility, retail dispensing, and fixed aircraft refueling operations. The delivery/movement of fuel dictated where and when the testing took place. Additionally, the ACM20 was configured for use on-line and used for IOS instrument calibration verification purposes.

CAA receives and stores JP-8 in two 400,000 gallon fuel storage tanks located at the bulk fuel storage facility. The JP-8 is delivered by commercial fuel tanker (averaging between 7,200-7,500 gallons per tanker) from the Buckeye Terminal in Indianapolis, Indiana. During the week of the demonstration, CAA had 10 tanker deliveries a day, as DLA-E increased the total storage volume for CAA to 1.3M gallons. The fuel offloaded is not filtered prior to storage.

JP-8 is transferred via a 0.5 mile underground pipeline from the bulk fuel storage facility to the Contractor Owned Contractor Operated (COCO) fuel facility operated by Hawthorne Services. The JP-8 flows through a filter separator and is then stored in one of two 350,000 gallon storage tanks. During the demonstration, fuel was transferred to the COCO facility twice with each transfer consisting of 150,000-160,000 gallons. The COCO facility is capable of retail dispensing into tanker trucks (including military HEMTTs) and fixed wing aircraft refueling arms. Filter separators are located at the retail dispenser and the fixed wing aircraft dispenser. Figure 3 provides a graphical layout the fuel distribution system and test points at CAA.

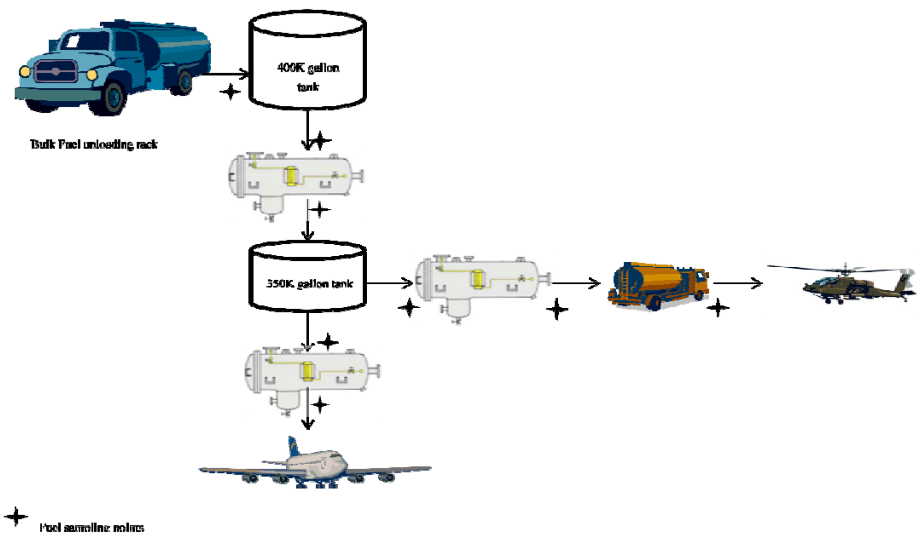

Figure 3. Fort Campbell Fuel System

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4. **Analysis**

4.1. Bulk Fuel Storage Facility

TARDEC began the demonstration at Campbell Army Airfield's (CAA) bulk fuel storage facility on Monday, 8 April 2013, and Tuesday, 9 April 2013. Ten (10) fuel tankers delivered JP-8 between 0900 hrs and 1300 hrs EST on both days. Each tanker consisted of 1 compartment and took approximately 30 minutes to offload. TARDEC tested the fuel from the pump station at the unloading rack as the fuel was being pumped from the tanker to the storage tank. The unloading racks are not covered and exposed to the elements (see Figure 4).

Figure 4. Campbell Army Airfield bulk fuel storage facility unloading rack

For each tanker (unless specified), testing included free water determination, matched weight monitor testing for particulate contamination by gravimetric analysis, IOS particle counting, and laboratory particle count instrument by bottle method. TARDEC employed the use of the Aviation Fuels Contamination Test Kit (AFCTK) to pull Aqua-Glo (free water) samples, matched weight monitors for gravimetric analysis, and the 1 gallon bottle sample. Free water determination was conducted in accordance with (IAW) ASTM D3240. A one-liter sample was filtered through the Aqua-Glo pad and tested using the D-2 Incorporated JF-WA1 Hydro-Light digital pad reader. Particulate contamination determination was conducted IAW ASTM D2276. In most cases, the collection vessel vents would begin to leak and the total volume of fuel filtered through the monitor ranged between 250-500mLs. Once the vessel began to leak, TARDEC terminated the sample collection and notated the total volume. Once sample collection was complete, the residual fuel was removed from the monitor, the plugs were replaced, the filter was placed in a re-sealable bag, and labeled for future analysis. All monitors were shipped back to TARDEC for analysis. IOS instruments were connected to the sample ports and the pumps were manually initiated to begin operation and data collection. Finally, a one (1) gallon fuel sample was collected from each tanker for testing the laboratory based instruments. Initially, TARDEC was using the fuel sampler from the AFCTK, Figure 5, to collect the sample, but changed the procedure to collect the fuel flowing through the IOS Figure 6. The procedure change is believed to have eliminated some of the contamination from the sampling source.

Figure 5. Fuel can with fuel sampler (6630-00-999-0753) and hose assembly (6630-00-999-0754) provided in the Army Aviation Fuel Contamination Test Kit (6630-01-008-5524).

Figure 6. Fuel can with hydraulic hose used for fuel sampling in an effort to reduce fuel contamination.

TARDEC was able to collect data from 9 of the 10 trucks on Monday, 8 April 2013. One truck was missed on 8 April because 3 tankers began offloading at the same time and operators were unable to get to the third truck in time. Of the nine (9) tankers sampled, seven (7) bulk fuel samples were analyzed by both the laboratory instrumentation and on-line with the IOS, one (1) bulk fuel sample only had a bottle sample taken for the laboratory instrumentation, and one (1) bulk fuel sample only collected data on the IOS instrument.

Figure 7 graphically shows the 4µm(c) ISO code for the laboratory instruments and the IOS data. Significant variation was seen in the data between the IOS instrumentation and the instruments utilized for testing the bottle samples in the laboratory environment. When performing an analysis of particle counts the smallest channel size is a crucial data point for reference as the >4µm cumulatively encompasses all the particulates present in the fuel greater than 4µm, for all instrumentations utilized in this demonstration the smallest channel is counts >4µm. The 4µm ISO codes for the laboratory instrumentation range from 4-6 ISO codes higher than the IOS instrumentation. The difference in the 4µm channel between the two types of instruments is believed to be caused by bottle contamination. The contamination issue will be discussed in more detail below. The gravimetric analysis of particulate contaminates performed via ASTM D2276, is shown in Figure 8. The data showed no correlation to the 4µm particle count data shown in Figure 7, but does show a degree of similar trending, as there was a sharp increase in particulates at 1130 hrs.

Also seen in Figure 7, the ACM20 instruments (blue line) are reporting lower particle counts in the 4µm channel than the Pamas S40 AVTUR instruments and the Stanhope-Seta AvCount instrument. TARDEC attributes the difference to calibration since the ACM20 instruments were calibrated to the lower end of the tolerance allowed by ISO 11171. However, the overall trending of the ACM20 instruments with the Pamas S40 AVTUR and Stanhope-Seta AvCount instruments indicates that values reported from all the instruments are valid measurements.

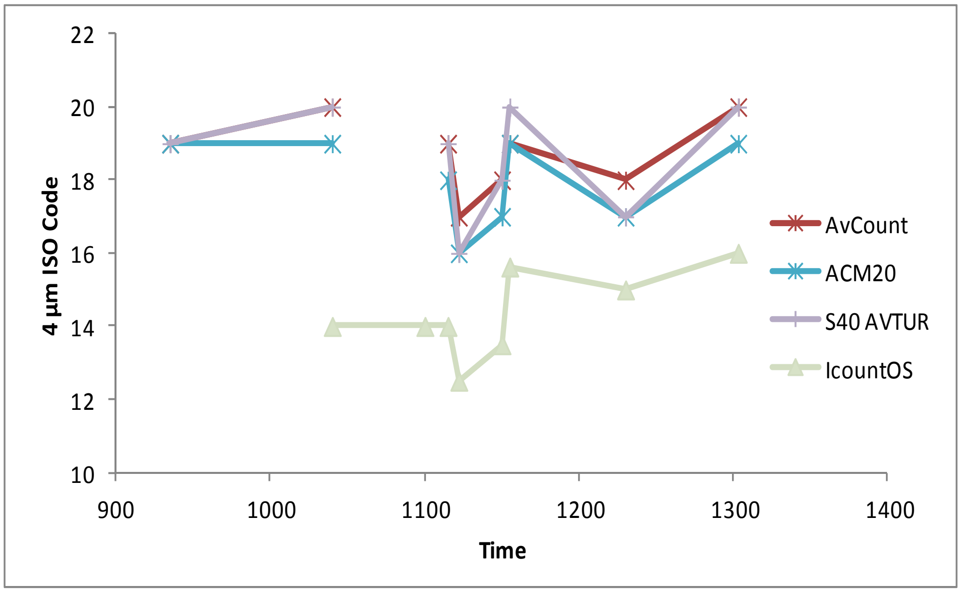

Figure 7. Fort Campbell Day 1 Particle Count Bulk Unloads 4µm ISO code data.

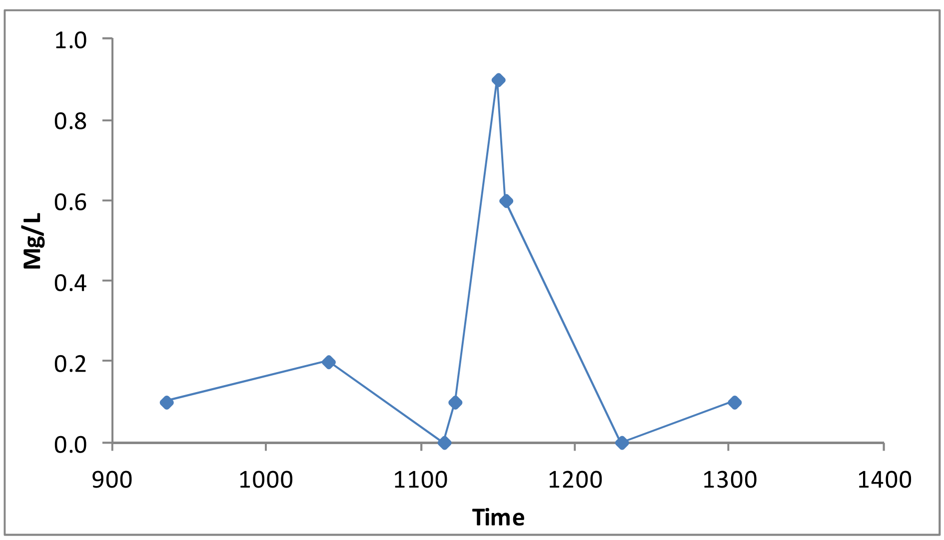

Figure 8. Fort Campbell Day 1 Bulk Unloads gravimetric analysis

TARDEC operators noted several sources of contamination for the bottle samples that could have attributed to the higher particle count readings for the laboratory instrumentation. First, the bottles used to collect the samples were brand new round gallon fuel cans purchased specifically for this demonstration. Not all of the bottles were not rinsed initially, but were reused over the course of the week, thus becoming clean. Additionally, the bottle samples used for the laboratory evaluation portion of this demonstration were subject to airborne contamination. Day 1 of the demonstration at CAA saw operators working in adverse weather conditions with winds ranging from 9-20 MPH with gusts up to 28 MPH, while a freshly poured concrete tarmac was being swept upwind of personnel taking fuel samples. Furthermore, the fuel sampling devices from the Army's Aviation Fuel Contamination Test Kit (AFCTK) were utilized as show in Figure 5. TARDEC believes that a combination of windblown dust into the sample containers, as well as, dust adhering to the Tygon F4040-A tubing contributed to the contamination of the fuel sample cans. To reduce this contamination, TARDEC collected the bottle samples using the high pressure hydraulic hose from the outlet of the IOS, Figure 6. The IOS readings and the bottle samples were collected simultaneously. This method was used for fuel sampling for the remainder of the testing Samples taken with the hydraulic hose sampling configuration saw a reduction in contamination, but most particle counts from the bottle samples were still higher than on-line sampling techniques due to environmental contamination.

TARDEC collected samples from ten (10) tanker trucks at the bulk fuel storage facility during the second day of testing at CAA. Data showed a significant decrease in variation between the laboratory instruments measuring the bottle samples and the on-line IOS unit as shown in Figure 9. The bottle samples showed a 3-4 ISO code decrease from the samples taken the previous day, while the on-line instrument data is still trending in the 12 to 16 ISO code region. The decrease in contamination may be a result of cleaner sample cans and the absence of dust from the cement cleaning as the operation was not continued on our second day of testing. Five (5) of the ten (10) samples evaluated on day 2 lay closely in line with bottle samples. The gravimetric analysis of particulate contaminates performed via ASTM D2276 is displayed in Figure 10, again shows no correlation to the 4µm particle count data shown in Figure 9, but does show a degree of similar trending. The two samples that had a gravimetric value exceeding 1.0mg/L pictured in Figure 11 and Figure 12 consisted of coarse particles that are greater than 30 microns and were visually identifiable and contributed to a large portion to the gravimetric mass.

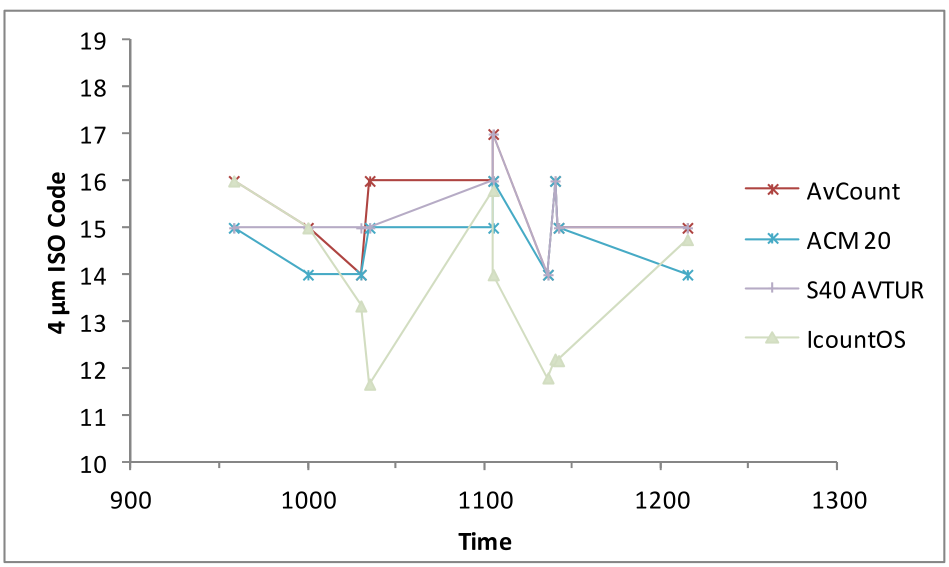

Figure 9. Fort Campbell Day 2 Bulk Unloads 4µm ISO code data

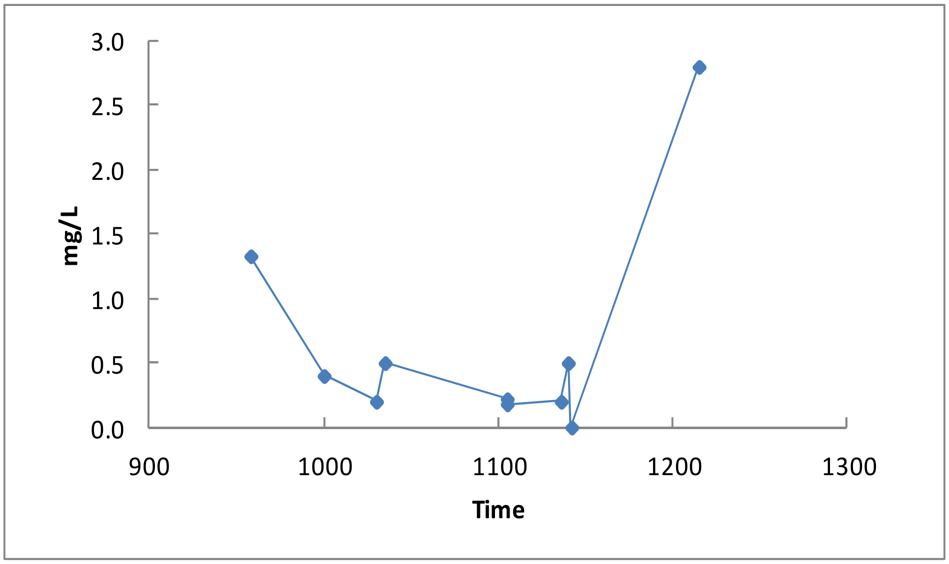

Figure 10. Fort Campbell Day 2 Bulk Unloads gravimetric analysis

Figure 11. Gravimetric sample 9 taken at 0958 hrs giving 1.33 mg/L, one large piece of dirt attributing to the high sample mass.

Figure 12. Gravimetric sample 18 taken at 1215 hrs giving 2.80 mg/L

4.2. Bulk fuel transfer to Contractor Owned Contractor Operated (COCO) facility

TARDEC collected data upstream and downstream of the filter separator during the transfer of JP-8 from the bulk fuel storage facility to COCO facility on 10 April 2013. The transfer began at 0815 hrs EST and continued until 150,000 to 160,000 gallons of fuel was moved. TARDEC was able to connect the IOS units to the filter separator about 15 minutes after the transfer started. The free water was measured at 0842 hrs EST both upstream and downstream of the filter separator. Both readings were 0.1ppm indicating the fuel was dry. TARDEC continued to test the transfer of fuel by the IOS online instruments and simultaneously collected the bottle samples for the laboratory instrumentation. Samples for gravimetric analysis were also pulled three times from upstream and downstream of the filter separator. The 4µm ISO code data is detailed in Figure 13, while Figure 14 provides details on 6µm ISO code data, and Figure 15 the 14µm ISO code data. This data is supplemented by the data in Table 2 which includes the bottle samples taken during this transfer at 0830 hrs, 0918 hrs and 1030 hrs. In most instances the 4µm channel data shows that the cumulative particulates downstream of the filter separator were less than the samples upstream of the filter. Figure 13 shows that the data from 0830 hrs to 0841 hrs that the filter separator is passing particulates downstream of the filter separator, this data compared to the data in Figure 14 where the downstream values are less than the upstream values for particles 6µm and larger indicates that the filter is passing particles smaller than 6µm but efficiently removing particles 6µm and larger.

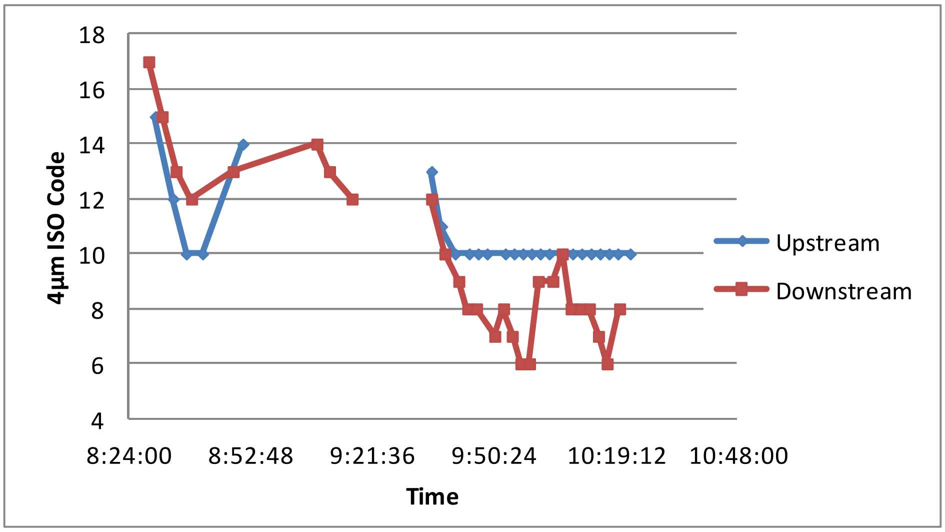

Figure 13. Bulk to COCO transfer 4µm on-line particle counts

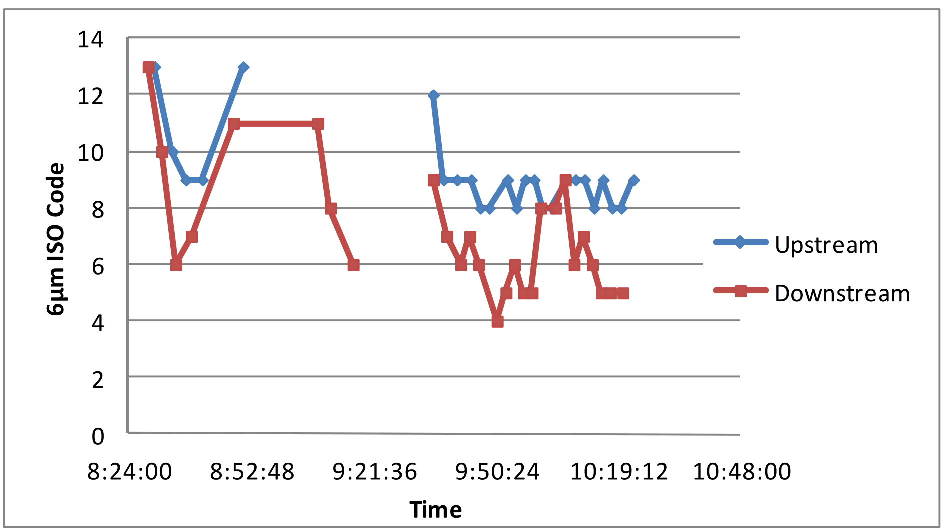

Figure 14. Bulk to COCO transfer 6µm on-line particle counts

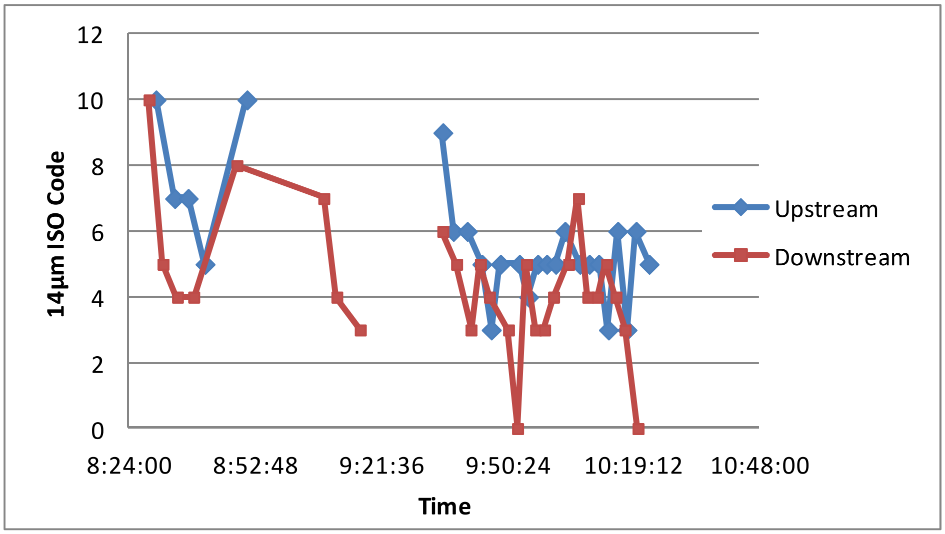

Figure 15. Bulk to COCO transfer 14µm on-line particle counts

Time (EST)	mg/L	Location	Lab ID	Avcount	ACM20 #1	ACM20 #2	S40 AVTUR #1	S40 AVTUR #2
830	1.11	Upstream	22	14/13/9/5	13/12/8/4	14/12/8/5	14/12/9/-	14/12/8/-
			22A	15/13/10/6	14/12/8/5	14/12/9/5	14/13/9/-	15/13/9/-
830	1.33	Downstream	23	14/12/9/4	13/12/8/4	14/12/9/5	14/12/9/-	14/12/9/-
			23A	15/13/10/7	14/12/9/5	14/12/9/5	15/13/10/-	15/13/9/-
918	0.60	Upstream	24	15/13/10/7	14/12/9/4	14/12/9/4	15/13/10/-	15/13/10/-
			24A	15/14/10/6	15/13/9/4	15/13/9/5	15/14/10/-	15/13/10/-
918	1.25	Downstream	25	15/13/9/5	14/12/8/4	14/12/8/4	14/13/9/-	14/12/9/-
			25A	16/14/11/7	15/13/8/7	15/13/10/6	15/14/10/-	15/14/10/-
1030	0.00	Upstream	26	14/12/9/5	14/12/8/0	14/12/8/4	14/12/9/-	15/12/9/-
			26A	15/13/10/6	14/13/9/4	14/13/9/5	15/13/10/-	15/13/10/-
1030	2.00*	Downstream	27	16/13/9/5	15/12/8/5	15/12/8/4	15/12/8/-	15/12/9/-
			27A	16/14/10/6	15/13/9/5	15/13/9/5	16/13/10/-	16/13/10/-

Table 2. Bulk to COCO transfer (bottle samples)
***sample port failure experienced while pulling sample 27. See gasket material in Figure 16.**

Figure 16. Gasket material found in gravimetric analysis from downstream sample port of Bulk-COCO transfer filter separator.

4.3. COCO Retail Fueling Station

On 9 April and 10 April 2013, TARDEC was able to monitor the transfer of fuel from the COCO facility storage tank to the retail dispensing station. Data was captured while dispensing into Hawthorne Services refueling trucks, which provides fuel for helicopters and fixed wing aircraft on the airfield. The refueling operations of the Hawthorne Services trucks took about 5 minutes as 4100-4500 gallons were pumped during each operation. The IOS instruments were connected upstream and downstream of the filter separator and the effluent was captured in sample cans for testing with the laboratory instrumentation. Samples for gravimetric analysis were also taken upstream and downstream of the filter separator. Once the trucks were full, TARDEC was able to test the fuel that was dispensed from the truck using the downstream filter separator on the truck. This data is presented in Table 3. Due to the limited amount of time that it takes for these trucks to be refilled (usually less than 5 minutes), data is in some instances is incomplete. The data showed in both instances of refueling the Hawthorne Services trucks that the downstream fuel samples have higher particle counts than the upstream fuel samples, for both the on-line and the laboratory samples. This data was not supported by the gravimetric loading of the matched weight monitors. The downstream samples off of the refueling truck did have a lower particle count than both the upstream and downstream samples from the filter separator located at the COCO retail stand.

Date	Time (EST)	mg/L	Location	Lab ID	Avcount	ACM20 #1	ACM20 #2	S40 AVTUR #1	S40 AVTUR #2	IOS
9 Apr 2013	1310	1.13	Upstream	20	16/14/11/7	15/14/10/6	15/14/10/5	16/14/11/-	16/14/11/-	12/10/7/3
				20A	16/15/11/7	16/14/10/7	16/14/10/7	16/14/11/-	16/14/11/-	
	1310	0.40	Downstream	19	18/16/12/8	17/15/11/7	17/15/11/6	17/15/12/-	17/15/12/-	13/11/8/6
				19A	18/16/12/8	17/15/11/7	17/15/11/7	17/16/12/-	17/15/12/-	
	1330	0.30	Truck Downstream	21	15/14/11/7	15/13/9/5	15/13/10/6	15/14/10/-	15/14/10/-	10/8/5/2
				21A	16/14/11/7	15/14/10/6	15/14/10/5	16/14/11/-	16/14/11/-	
10 Apr 2013	1324	0.38	Upstream	29	16/14/11/7	15/13/10/5	15/13/10/6	15/13/10/-	15/13/11/-	
				29A	16/14/11/8	15/14/10/7	15/14/10/6	16/14/11/-	16/14/11/-	
	1324	0.00	Downstream	28	17/15/11/7	16/14/10/5	16/14/10/6	17/14/11/-	17/15/11/-	
				28A	17/15/11/7	17/14/10/7	17/14/10/7	17/15/11/-	17/15/11/-	
	1115	-	Truck Downstream	-						11/8/6/0

Table 3. Upstream and downstream data of fuel being loaded onto Hawthorne Services refueling truck and downstream data of fuel being dispensed from the Hawthorne Services refueling truck.

On Friday, 12 April, Hawthorne Services refueled a Lockheed C-5 Galaxy aircraft. TARDEC was able to capture fuel samples from upstream and downstream of the filter separator at the COCO retail dispensing station as three trucks were fueled. These trucks were then used to refuel the C-5 aircraft. Figure 17 provides the IOS data for these fuel samples. Similar to the data in Table 2, Figure 10 occasionally shows the 4µm data from the fuel downstream of the filter separator contains higher levels of particulates than fuel upstream of the filter separator. Thus, supporting the data found in Table 3. Figure 18 and Figure 19 show the 6µm and 14µm channels indicating that the filter separator is efficiently removing particles greater than 5 µm. The gravimetric analysis data shows that the filter separators appear to be capturing the majority of particles that it is encountering. Matched weight monitor for the upstream taken on 12 April 2013 shown in Figure 20, course particulates are clearly visible to the naked eye.

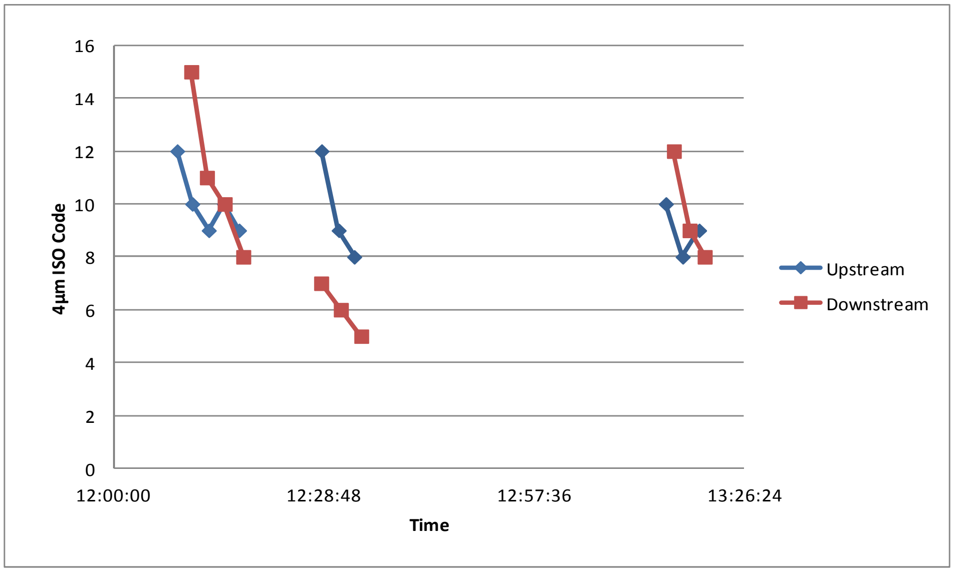

Figure 17. C5 aircraft refuel via three trucks 4µm ISO Code.

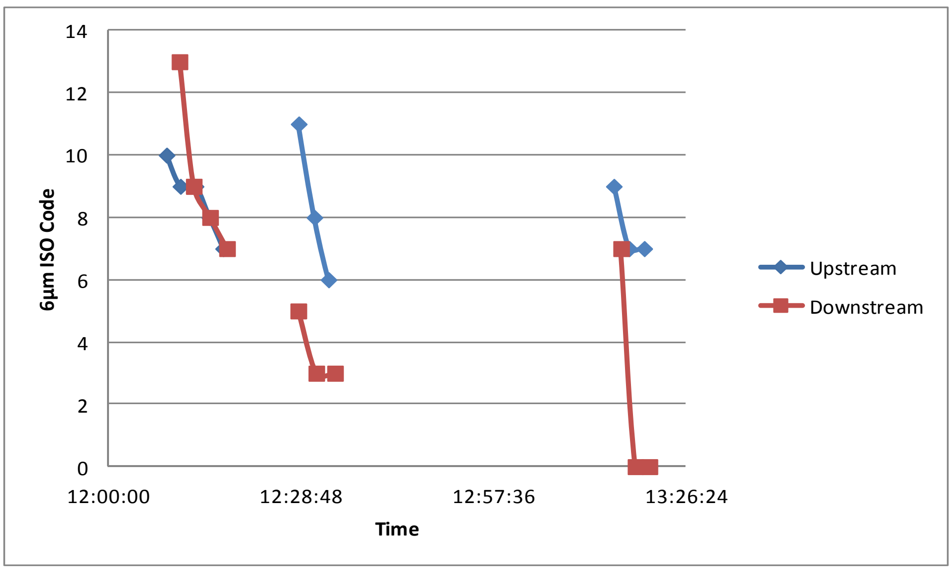

Figure 18. C5 aircraft refuel via three trucks 6µm ISO Code.

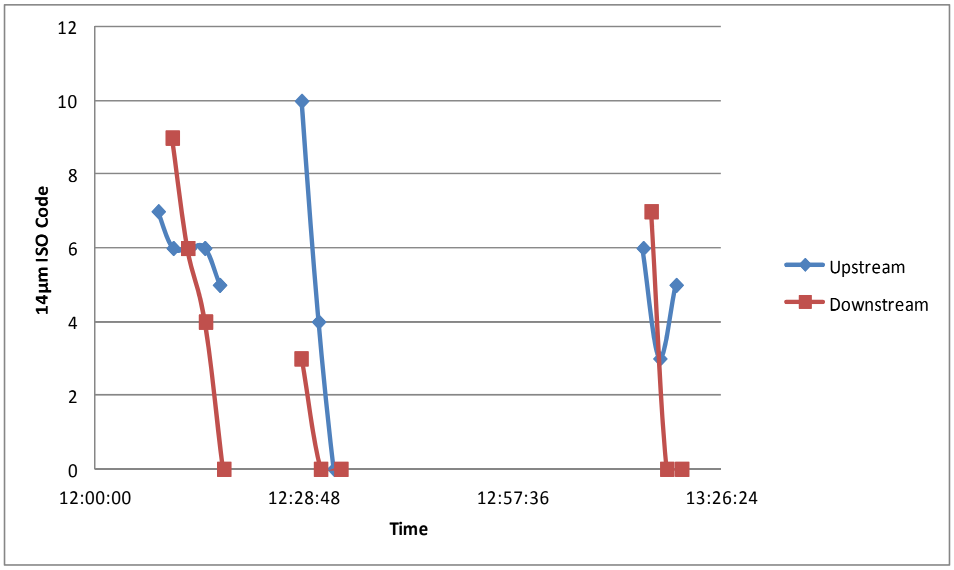

Figure 19. C5 aircraft refuel via three trucks 14µm ISO Code.

Figure 20. Matched weight monitor for the upstream taken on 9 April 2013 course particulates clearly visible to the naked eye contribute to the 1.13 mg/L gravimetric mass.

4.4. On-line evaluation of ACM20 particle counter

In an attempt to establish the cause of the variation between the on-line instrument and the laboratory instruments seen in Figure 7 and to some extend in Figure 9 the Parker ACM20 instrument was configured for on-line measurements and taken to perform evaluations at several locations throughout the fuel distribution system.

The second fuel transfer from the bulk fuel storage facility to the COCO facility consisted of 160,000 gallons of fuel on Friday, 12 April 2013. The transfer was captured at the upstream sample port with the Parker ACM20 and the IOS instrument. The data is detailed in Figure 21, with the ACM20 data taken at 0907 hrs and 0909 hrs EST. This data is supplemented by the data in Table 4 which includes the bottle samples taken during these transfers at 0845 hrs and

0900 hrs EST. The data shows that the IOS units were reading in concurrence with the ACM20 instrumentation, and that the elevation of data seen in the laboratory instrumentation is indeed caused by sample bottle contamination.

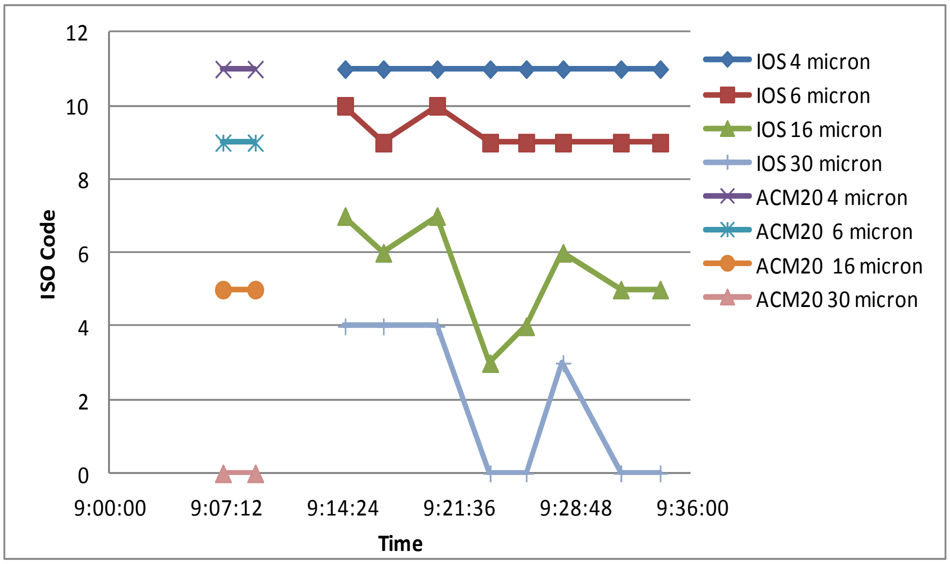

Figure 21. On-line instrument evaluation of bulk to COCO transfer

Time (EST)	Location	Lab ID	Avcount	ACM20 On-line	ACM20 #1	ACM20 #2	S40 AVTUR #1	S40 AVTUR #2
845	Upstream	32	17/15/11/7		15/13/9/5	15/13/9/5	16/14/10/-	16/14/10/-
		32A	17/15/11/7		16/14/10/6	16/14/10/6	16/14/11/-	16/14/11/-
900	Upstream	33	16/14/10/7		16/14/10/0	16/14/10/4	17/14/11/-	17/14/11/-
		33A	17/15/11/8		16/14/10/5	17/14/10/5	17/15/11/-	17/15/11/-
907	Upstream			11/9/5/0				
909	Upstream			11/9/5/0				

Table 4. Bulk to COCO transfer on-line ACM20 evaluation and laboratory bottle sample data.

Additionally, the Parker ACM20 and the IOS instruments were also tested during at the Bulk Fuel Storage Facility during two tanker truck bulk unloads on Friday, 12 April 2013, to verify the IOS instrument calibration. The data is provided in
Figure 22 and Figure 23. The ACM20 data was taken at 1040 and 1047 EST respectively. This data is supplemented by the data in Table 5 which includes the bottle samples taken during these transfers at 1014 hrs and 1030 hrs EST. The data in Table 5 supports the notion for the potential for fuel sample contamination during the bottle sampling process; where the laboratory samples are give a higher reading than the corresponding on-line samples.

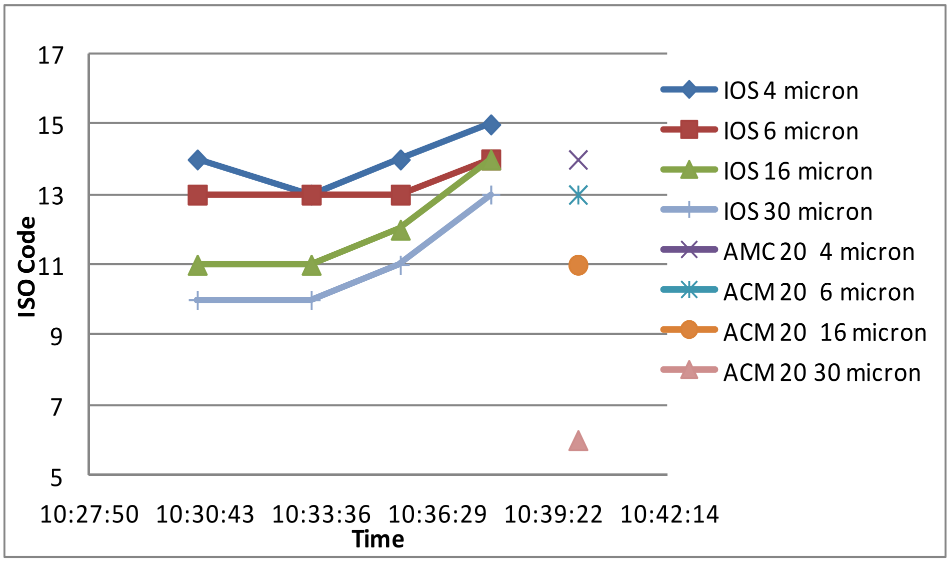

Figure 22. Truck 6 unload at bulk with IOS and ACM20 data at 1040 hrs EST.

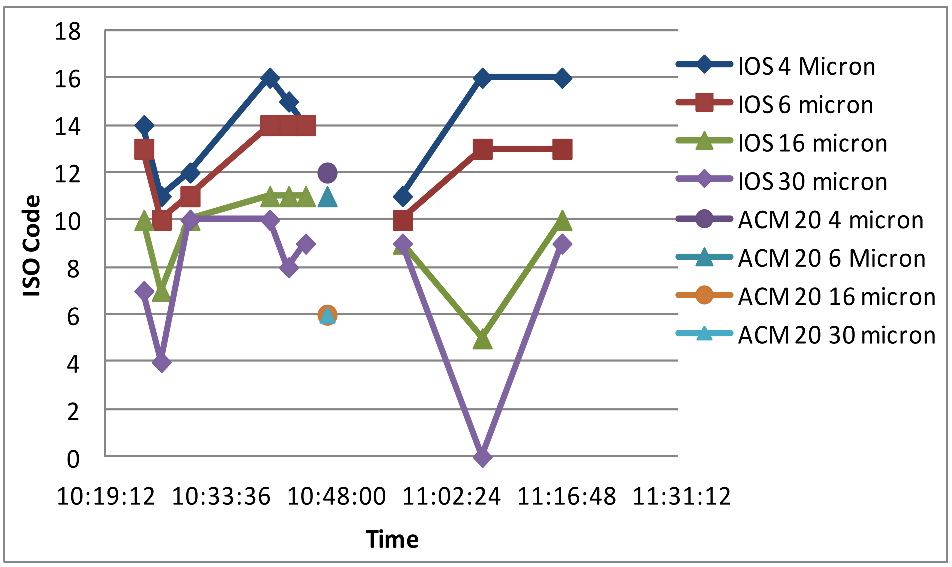

Figure 23. Truck 7 unload at bulk with IOS and ACM20 data at 1047 hrs EST.

Time (EST)	Truck	Location	Lab Unit Run ID	Avcount	ACM-20 On-line	ACM-20 #1	ACM-20 #2	S40 AVTUR #1	S40 AVTUR #2
1014	6	Bulk	35	16/14/11/9	14/13/11/6	16/13/11/10	16/13/10/8	16/14/12/-	16/14/11/-
			35A	17/14/12/11		16/14/12/12	16/14/12/11	16/14/13/-	16/15/13/-
1030	7	Bulk	36	17/14/11/9	12/11/6/6	16/14/10/6	16/14/10/6	16/14/11/-	16/14/11/-
			36A	17/15/11/9		16/14/10/6	16/14/10/6	17/15/11/-	17/14/11/-

Table 5. Truck 6 and 7 unload at bulk bottle samples

4.5. Fixed wing aircraft refuel

On Thursday, 11 April 2013, a Boeing C-17 Globemaster III was refueled via one of the two fueling arms located at the COCO facility. The C-17 was ordered to receive 27,000-28,000 gallons of JP-8 and the refueling operation took about 30 minutes. It should be noted that heavy precipitation was experienced during the refueling operation. TARDEC connected IOS units upstream and downstream of the filter separator and collected the bottle samples as previously discussed. The sampling cans were covered in black trash bags to reduce water contamination. The IOS data is displayed in Figure 24 and the laboratory particle counter data taken from the IOS effluent from the first 10 minutes of refueling, is provided in
Table 6. The IOS data indicates that fuel downstream of the filter separator has a higher particulate load than the fuel upstream, of the filter separator. The laboratory particle count data indicates that contaminate loads appear to be lower downstream of the filter separator, while the gravimetric data shows nearly 0.5 mg/L drop in particulates downstream of the filter separator.

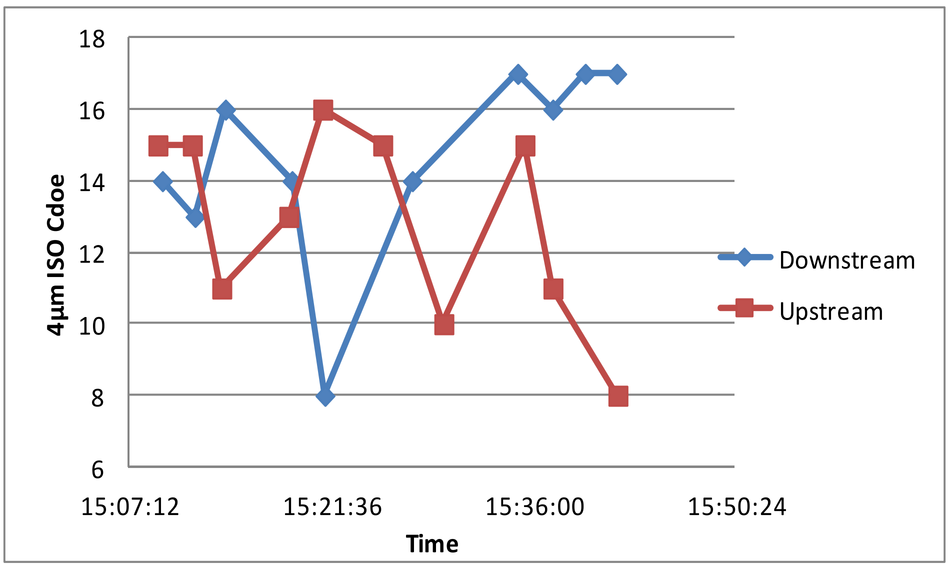

Figure 24. Boeing C-17 Globemaster III refuel on-line 4µm IOS data.

Time (EST)	mg/L	Location	Lab ID	Avcount	ACM-20 #1	ACM-20 #2	S40 AVTUR #1	S40 AVTUR #2
1511	0.70	Upstream	31	16/14/10/7	16/13/10/7	16/13/10/6	16/14/10/-	16/14/10/-
			31A	17/14/11/7	16/14/10/6	16/14/10/6	16/14/11/-	16/14/10/-
1511	0.25	Downstream	30	16/14/11/7	15/13/10/6	15/13/10/5	16/14/10/-	16/14/11/-
			30A	16/14/11/7	16/14/10/6	16/14/10/6	16/14/11/-	16/14/11/-

Table 6. Boeing C-17 Globemaster III refuel laboratory data.

5. **Conclusion**

Light obscuration particle counter technologies are able to properly measure solid particles and provide an indication of particulate content levels present in fuels, and may be an appropriate replacement for the Army's existing filter effectiveness testing. Data shows that to efficiently monitor filter effectiveness, testing should be completed upstream, as well as, downstream of the filter separator. Particle counts were not correlatable to the gravimetric measurements. All the gravimetric samples having a weight greater than 1.0 mg/L had significant quantities of course particulates contributing to particulate mass. These course particles were not accurately accounted for in the particle count readings. The IOS data shows a non-homogeneity of contamination throughout fuel movements which indicates that the fuel sampled for the particulate contaminant in aviation fuel by line sampling test may have a different contaminate load than fuel sampled by the particle counters, and that the standard ASTM test method does not provide a representative sample of the fuel as a whole.

Significant variation was seen between on-line samples and bottle samples. This variation was shown to be caused by the bottle sampling process. Although almost all fuels fell below the Army's proposed 19/17/14/13 ISO code limits, this limit was developed for on-line sampling, an error window allowing for a higher contamination levels may be appropriate for bottle samples.

Additional testing on tactical fuel handling equipment is recommended.

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List of Symbols, Abbreviations, and Acronyms

µm	Micrometer
AFCTK	Aviation Fuel Contamination Test Kit
AL	Alabama
ASTM	ASTM International
AUST	Australia
CAA	Campbell Army Airfield
COCO	Contractor Owned Contractor Operated
DEF	Defence/Defense
DLA-E	Defense Logistics Agency – Energy
DTL	Detail
EI	Energy Institute
EST	Eastern Standard Time
HEMTT	Heavy Expanded Mobility Tactical Truck
hrs	Hours
IOS	IcountOS
ISO	International Organization for Standardization
JP-8	Jet Propellant 8
KY	Kentucky
mg/L	Milligrams per Liter
MIL	Military
MPH	Miles Per Hour
PPM	Parts Per Million
STAN	Standard
STD	Standard
TARDEC	Tank Automotive Research Development and Engineering Center
U.S.	United States
UK	United Kingdom